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ABSTRACT

The four sections of this paper provide an analysis of the structure of human memory. The first section, intended to provide a clear example of personal memory, examines a hypothetical episode in the life of an undergraduate student, and shows how one episode can give rise to three different forms of memory: personal, semantic, and rote linguistic. The second section develops a "botany" of important naturally occurring forms of memory and contrasts descriptions of six types of memory (personal, semantic, generic perceptual, motor, cognitive, and rote linguistic) with the traditional distinction between episodic and semantic memory. The third section decomposes the important naturally occurring types of memory and attempts to construct a table of the logically possible types of human memory. It organizes human memory in terms of the types of inputs and types of acquisition conditions and proposes an account of the possible forms of memory representation in terms of the intersections of these two factors. The final section relates the initial botany of memory to a more analytic classification scheme and discusses the mental processes involved in transferring information from procedural memory to semantic memory and the problem of the veridicality of mental images. (HOD)

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Technical Report No. 321

THE STRUCTURE OF HUMAN MEMORY

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August 1984

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The Structure of Human Memory

The overall purpose of this article is to provide an analysis of the structure of human memory. We will focus primarily on the process of recall of information from long-term memory.

In the first section of the paper we examine a hypothetical episode in the life of an undergraduate. The episode is intended to provide a clear example of personal memory, a type of memory rarely studied in experimental psychology. It also shows how one episode can give rise to three different forms of memory: personal memory, semantic memory, and rote linguistic skill.

In the second section we develop a "botany" of important naturally occurring forms of memory. We make an explicit methodological commitment to use the phenomenal reports of subjects as one major class of evidence in our analysis. Our description reveals six important types of memory: personal memory, semantic memory, generic perceptual memory, motor skill, cognitive skill, and rote linguistic skill. We contrast this description with the traditional distinction between episodic and semantic memory. We conclude that the term episodic memory, as it is currently used, includes two very different forms of memory--personal memory and skill.

In the third section we provide a more analytic approach to the structure of human memory. We decompose the important

naturally occurring types of memory and attempt to construct a table of the logically possible types of human memory. This analysis organizes human memory in terms of the types of inputs and types of acquisition conditions, and proposes an account of the possible forms of memory representation in terms of the intersections of these two factors. A systematic attempt is made to examine both imaginal and nonimaginal forms of representation for each form of memory. The analysis captures a wide variety of types of memory and the forms of representation postulated to underlie each type.

In the final section we relate the initial botany of memory to our more analytic classification scheme. We discuss the mental processes involved in transferring information from procedural memory to semantic memory. We point out the complexity that can arise from our assumptions about multiple forms of representations and finally we discuss the problem of the veridicality of mental images.

AN EXAMPLE

The analysis of memory outlined in this article is quite different from most current approaches in psychology, and so to display some of the differences, we will work through a concrete example illustrating three of the basic forms of memory that will occur in our treatment.

The Episode

Consider the following event: A University of Illinois undergraduate comes in the side door of the Psychology Building. He takes the elevator to the fourth floor. He pulls a slip of paper out of his pocket, checks the room number, and walks down the corridor to the experimental room. He hesitates a minute, knocks on the door, and goes inside. He sees the experimenter standing behind a table that contains a memory drum. He sits down and is given 20 trials of practice on a long paired-associate list. One of the items on the list is the pair DAX-FRIGID. After the experiment is over, he gets up, gives a sigh of relief, and leaves the experimental room.

Three Types of Memory

This episode can be used to illustrate how the same event can lead to the development of three forms of memory: personal memory, semantic memory, and rote linguistic skill.

Personal Memory

If, the next day, we were to ask this undergraduate, "Do you remember the psychology experiment you were in yesterday?" he might say something like: "Sure, I remember coming in the side door on Sixth Street. I turned to the right and took the elevator up. It was my first experiment. I couldn't remember the room number so I had to check my experiment notice. I remember feeling nervous as I stood there in front of the door. I remember opening the door and seeing the experimenter standing

behind the table. I remember being surprised that the experimenter was a woman. She had a white laboratory coat on, etc." If we asked the undergraduate, "Was anything going through your mind while you were telling us about the experiment?" he would probably say something like: "Yes, as I was recalling the information I could see in my mind's eye much of what I told you. I could see the door on Sixth Street. I could see the expression on the experimenter's face when I opened the door." It is this type of memory that will be called personal memory in this paper.

Semantic Memory

If, some months later, we were to ask this undergraduate, "Do you remember what psychology experiments you were in last semester?" he might say, "Sure, there was a verbal learning experiment, a perception experiment, and two social psychology experiments." If we asked him, "Was anything going through your mind when you told me you were in the verbal learning experiment?" he would probably say something like: "No, I just know that there were four experiments and one of them was a verbal learning experiment. Now that we are talking about it, I can see the experimenter in her white coat standing behind the table, but nothing like that was happening when I answered your question." His initial recall is an example of the type of memory that we will call semantic memory.

Rote Linguistic Skill

We can illustrate the third form of memory by asking our undergraduate to perform the following task: "I am going to give you a series of nonsense syllables from that experiment you were in several days ago, and when I give you a nonsense syllable I want you to tell me the word that was paired with it." We then give the undergraduate a series of items from the experimental list including the item DAX. When presented with the nonsense syllable DAX, our undergraduate says "FRIGID." If we ask him, "Was anything going through your mind when you gave the response 'FRIGID'?" he might say something like: "No, I had been over that blasted list so many times that I was able to say it as soon as you showed me the stimulus." This type of memory is rote linguistic skill.

Strategy of the Paper

The purpose of the description of the visit to the psychology lab has been to provide a detailed example of some of the types of memory that will be discussed later in the paper. However, it also illustrates two general strategies adopted throughout this chapter. We are looking for naturally occurring categories of memory phenomena, and we take the phenomenal reports of subjects as one important class of data to be used in the study of human memory.

Data from Phenomenal Reports

In the last decade there has been a growing acceptance of the position that reports of phenomenal experience can be used in scientific psychology (Ericsson & Simon, 1980; Hilgard, 1980; Natsoulas, 1970, 1974; Radford, 1974). The general line of argument is that phenomenal reports are as acceptable as any other type of data. As long as the data from phenomenal reports enters into lawful relations with other data, and as long as theoretical constructs derived from phenomenal experience interact in a meaningful fashion with other theoretical constructs, there is no reason to exclude them from scientific psychology. We agree with these arguments derived from philosophy of science and from methodological considerations, but we wish to push the issue one step farther. We take the position that a complete scientific psychology must be able to account for the data from phenomenal experience and that an information-processing account of the mind that excluded the data from phenomenal experience would be an incomplete science (see Block, 1980; Shoemaker, 1980, for a similar line of argument in philosophy).

It also seems to us that there has been some divergence between the acceptance of phenomenal reports in theory and the actual use of them in practice. Even though cognitive psychology is considered to be a mentalistic psychology, the focus on unconscious mental processes within the information-processing

tradition has led to remarkably little serious use of data from phenomenal experience (see Dulany, 1968, for an early counterexample). This avoidance of data from phenomenal experience is very pervasive. Our analysis in this article of some recent experiments by the senior author relies on unsystematic phenomenal reports made by the subjects after the formal experiment was over. Clearly, in the course of gathering the data in those experiments the phenomenal report data were not considered to have the same scientific status as the data on the number of correct responses in recall.

Recently we have initiated a series of experiments explicitly designed to gather phenomenal reports during a variety of recall tasks (Brewer & Pani, 1982, 1983b). The basic methodology is to ask subjects a memory question (e.g., "What is the opposite of false?" or "Which is farther south, the tip of Texas or the tip of Florida?") and then request descriptions of their mental experience during recall.

A BOTANY OF MEMORY

Purpose

In this section of the article we take an explicitly morphological approach to human memory. We want to find the common forms of human memory and provide careful descriptions of them, much as a biologist might describe the obvious species occurring on a newly discovered island. In this section we will

not discuss how the types of memory might have developed or what mechanisms might underlie their operation.

This approach is rarely taken by experimental psychologists and so to help inform our observations we have explored a number of literatures outside of current cognitive psychology. The particular description of memory that we outline below has been most strongly influenced by: (a) our own introspections; (b) the work of philosophers on memory (e.g., Bergson, 1911; Furlong, 1951; von Leyden, 1961; Locke, 1971; Malcolm, 1963; and Russell, 1921); (c) the early research of introspective psychology (e.g., Crosland, 1921; Kuhlmann, 1907, 1907, 1909; Titchener, 1910); and (d) current cognitive psychology (Neisser, 1976; Norman, 1976; and Tulving, 1972).

We consider our proposed classification to be tentative. One reason for this is that we do not have systematically obtained phenomenal reports concerning memory, and therefore we have had to rely on our own and others' unsystematic observations.

Six Types of Memory

We will now turn to the botany of memory and describe six types of human memory. Table 1 gives examples of questions intended to elicit these six types of memory.

Insert Table 1 about here.

Personal Memory

A personal memory is a recollection of a particular episode from an individual's past. Personal memory seems always to be experienced in terms of some type of mental imagery—predominantly visual, since vision is the dominant sense (e.g., "I could see the expression on the experimenter's face," in the above example). Personal memory includes some nonimaginal information also (in the above example: "It was my first psychology experiment"). The memory is experienced as the representation of a particular time and location. Indeed, it often seems to be a kind of "reliving." In the case of time, this does not mean that the individual can assign an actual date to the memory, just that it is experienced as having been a unique time. For location, the ability to actually recall a particular place seems much stronger, but data are needed here. The personal memory episode is accompanied by a propositional attitude (cf., Fodor, 1978) that "this episode occurred in the past." A personal memory is accompanied by a belief that the remembered episode was personally experienced by the individual (thus the term "personal memory"). A personal memory is also frequently accompanied by a belief that it is a veridical record of the original episode. This is not to say that personal memories are veridical, just that they are frequently believed to be. We will discuss the veridicality issue later in the article.

Generic Memory

A generic memory is the recall of some item of the individual's general knowledge. Generic memory is not experienced as having occurred at a particular time and location. Two important forms of generic memory are semantic memory and perceptual memory.

Semantic memory. Semantic memory is the subclass of generic memory that involves memory of abstract knowledge. Examples are the knowledge underlying the statement, "the speed of light is a constant," and "I have always avoided abstractions." Philosophers, logicians, and psychologists have frequently represented this type of abstract knowledge with some form of propositional notation. Recalling information from semantic memory is not typically accompanied by an experience of mental imagery. However, if the knowledge required is strongly associated with highly imageable information one may experience imagery during recall (i.e., in answering the question "What is the capital of France?" one might have an image of the Eiffel Tower).

Perceptual memory. Perceptual memory is the subclass of generic memory that involves the memory of generic perceptual information. Examples are the information contained in a generic perceptual memory of a map of the United States or of the capital letter "E." Recalling information from generic perceptual memory is typically experienced in terms of mental imagery. For example, if asked "What state is directly to the south of

Oklahoma?" or "How many corners in a capital letter 'E'?" most people report experiencing a "generic visual image." The generic images are not typically experienced as involving a particular time and location. Both personal memory and generic perceptual memory have consistent mental image properties but they involve somewhat different phenomenal experiences. For example, a generic image will tend to be a figure without an imaginal ground, irrelevant attributes may not be present and it more often occurs in a single modality.

Skill

A skill is the ability to carry out a practiced motor performance or cognitive operation. When skilled actions are carried out there is typically no experience of mental imagery. Three important types of skills are motor skills, cognitive skills, and rote linguistic skills.

Motor skill. Motor skills can involve the execution of a single motor action or a complex sequence of motor actions. An example of a simple motor skill would be pressing the "K" key on a computer to make the Pac Man figure go right, or pushing the gear shift lever to put a car in reverse. An example of a more complex motor skill would be the skill involved in swimming or playing tennis. Note that the complex motor skills are generative, in the sense that if a tennis ball arrives in some unique position a skilled tennis player can hit it with a motor action never previously produced.

Cognitive skill. Cognitive skills involve the execution of practiced cognitive operations. These skills are generative in the sense that the cognitive operations can be applied to a class of new instances, and that class may be indefinitely large. Examples of cognitive skills are taking the square root of a number, and making the subject and verb of English sentences agree in number.

Rote linguistic skill. Rote linguistic skill involves the ability to produce surface structure linguistic objects. This skill differs from motor skills and cognitive skills in several important respects. The skill deals with the meaningless surface structure aspects of particular linguistic objects and it is not generative. Having learning a rote skill is simply to have mastered a given set of surface linguistic objects, and it does not allow generative transfer to a new set of surface linguistic objects. Examples of rote skills are the ability to say the alphabet and to give one's social security number.

Reflections of the Classification in Ordinary Language

A number of philosophers (Locke, 1971; Malcolm, 1963) have suggested that there are linguistic "tests" for the three fundamental categories of memory outlined above (i.e., personal memory, generic memory, and skill). Apparently these memory categories are fundamental enough so that the ordinary language reflects the differences among them. The three linguistic frames are: "I remember X"; "I remember that X"; and "I remember how to

X." Personal memory statements tend to be acceptable in the first frame, but not the second two. Thus, "I remember the expression on the experimenter's face" and *"I remember that the expression on the experimenter's face" and *"I remember how to the expression on the experimenter's face." Generic memory statements tend to be acceptable in the first and second frames, but not in the third. Thus, for semantic memory "I remember the speed of light is a constant" and "I remember that the speed of light is a constant," but *"I remember how to the speed of light is a constant." Similarly for generic perceptual memory: "I remember Texas is directly to the south of Oklahoma" and "I remember that Texas is directly to the south of Oklahoma," but *"I remember how to Texas is directly to the south of Oklahoma." Motor and cognitive skill statements tend to be acceptable in the third frame, but not the first two. Thus, for motor skills, "I remember how to swim," but *"I remember swim" and *"I remember that swim." For cognitive skills, "I remember how to take the square root of a number" but *"I remember take the square root of a number" and *"I remember that take the square root of a number." Rote linguistic statements tend to be acceptable in the first and third frames. Thus "I remember the alphabet" and "I remember how to say the alphabet," but *"I remember that the alphabet." While these tests do not work all the time, the fact that they work as well as they do is impressive. The fact that the ordinary language reflects the memory distinctions provides

independent evidence that these are important categories of our mental life.

Memory Classifications by Psychologists

In this section we want to examine two major landmarks in the analysis of memory phenomena: the position of Ebbinghaus (1885/1964) in the first experimental investigation of memory, and Tulving's (1972) more recent distinction between episodic and semantic memory.

Ebbinghaus

In the first chapter of the Ebbinghaus monograph on human memory he discusses three forms of memory. He identifies one form that seems closest to personal memory as outlined above. He says,

> Mental states of every kind--sensations, feelings, ideas--which were at one time present in consciousness and then have disappeared from it, have not with their disappearance absolutely ceased to exist . . . [we] can call back into consciousness by an exertion of the will directed to this purpose the seemingly lost states (or, indeed, in case these consisted in immediate sense-perceptions, we can recall their true memory images). (1885/1964, p. 1)

Ebbinghaus' second form of memory was an involuntary type of personal memory which is not relevant to this discussion. The final form of memory outlined by Ebbinghaus was similar to skill as it was discussed above. He states,

> there is a third and large group to be reckoned with here. The vanished mental states give indubitable proof of their continuing existence even if they themselves do not return to consciousness at all . . . The boundless domain of the effect of accumulated experiences belongs here.
> (1885/1964, p. 2)

In the section of the monograph related to the methods of the natural sciences Ebbinghaus argues that psychologists should study skills because the study of this type of memory requires "less dependence upon introspection" (p. 8). In fact, Ebbinghaus went on to suggest that in studying skill the method of recall was too likely to be influenced by conscious mental processes, and so he chose to use the method of savings (i.e., the improvement in the speed of learning of a task due to previous trials with the task). While later researchers decided that Ebbinghaus had been a little too limited in not allowing recall techniques, they essentially accepted the methodologically motivated focus on skill. For 80 years the experimental study of memory was the study of rote linguistic skill, with an occasional study of motor skills (e.g., McGeoch & Irion, 1952; Melton, 1964).

Tulving

In the late 1960's a few psychologists (e.g., Collins & Quillian, 1969) were able to break out of the Ebbinghaus emphasis on skill and began to carry out experiments that tested semantic

memory. The relationship of these studies to the traditional verbal learning experiments remained a puzzle for a few years until Tulving's insightful paper in 1972. Tulving pointed out the differences between the traditional verbal learning experiments and the new semantic memory experiments, and proposed that the differences be formulated in terms of a distinction between semantic memory and episodic memory.

Semantic memory. Tulving states that semantic memory is "the memory necessary for the use of language . . . [the] organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them" (1972, p. 386). The definition of semantic memory given in our botany clearly follows Tulving's usage, although we tend to de-emphasize the focus on linguistic information and instead treat semantic memory as memory of all abstract things.

The other major way in which our classification differs from Tulving's is that we consider that an individual's overall general knowledge covers more than just semantic memory. Thus, in our classification we have adopted the term generic memory for the broader class of general knowledge (see Hintzman, 1978, and Schonfield & Stones, 1979, for a similar view) and retained the term semantic memory for the subclass of memory for abstract things. One important advantage for our approach is that it allows us to treat the important class of generic perceptual

information and thereby to incorporate ordinary memory phenomena such as the occurrence of "mental maps."

While we have disagreed with some aspects of Tulving's construct of semantic memory, one should not lose sight of the importance of this construct in the development of psychological theories of memory. By distinguishing semantic memory from other types of memory Tulving recognized that recall of general knowledge is one important type of memory that must be included in a successful description of the form of human memory.

Episodic memory. While Tulving's description of semantic memory clarified thinking about memory for generic knowledge, his account of episodic memory has definite problems. Tulving states that episodic memory "stores information about temporally dated episodes or events and temporal--spatial relations among these events" (1972, p. 385) and proposes that instances of episodic memory refer "to a personal experience that is remembered in its temporal-spatial relation to other such experiences" (p. 387). It seems fairly clear that when Tulving gives an abstract definition of episodic memory he is describing personal memory as outlined in our classification.

The problem arises when one examines the examples of episodic memory given in his paper. One of four examples was the statement "Last year, while on my summer vacation, I met a retired sea captain who knew more jokes than any other person I have ever met" (p. 386). Taken at face value this appears to be

an example of generic memory as we have used the term. The statement seems to refer to Tulving's knowledge that he met a sea captain during his last summer vacation. A clear example of personal memory would have been a statement such as "I remember sitting on the bar stool, drinking a hot toddy, while he told me the travelling sailor joke, etc." One of the other of the four examples suggests a deeper problem. This example is "I know the word that was paired with DAX in this list was FRIGID" (p. 387). In terms of our classification this is either an example of generic memory ("I remember that DAX was the syllable paired with FRIGID") or an example of a rote linguistic skill (given the item DAX the subject produces "FRIGID"). Since Tulving was using this example as an instance of episodic memory, he must not have intended the generic memory interpretation. This leaves the rote skill interpretation. This classification of an instance of rote skill under the heading of episodic memory apparently reflects a general decision on Tulving's part to classify rote skill as a type of episodic memory, since Tulving explicitly states (p. 402) that traditional verbal learning experiments are to be considered to be experiments investigating episodic memory.

Thus, in terms of the memory classification we have outlined above, Tulving's treatment of episodic memory is inconsistent. Tulving's formal definition of episodic memory seems very close to our definition of personal memory, yet the examples given and the classification of the traditional laboratory experiments as

instances of episodic memory are inconsistent with his definition. Nevertheless, virtually every psychology text written since Tulving's classic paper quotes his definition of episodic memory, and then states that the memory experiments in the Ebbinghaus tradition are all examples of episodic memory.

Examination of our initial example of the undergraduate going to the psychology experiment shows the problems produced by this inconsistency with respect to personal memory and skill. Our hypothetical undergraduate had 20 trials on a long paired-associate list that resulted in the development of the rote verbal skill of producing the responses when given the stimuli. We argued that the undergraduate would probably have a strong personal memory of coming to the building and starting the experiment, but it seems to us highly unlikely that the undergraduate could have a personal memory for a particular trial, say Trial 13, in the series. It would appear that the conditions for the development of skill are, in fact, antithetical to the development of personal memory (this issue will be discussed again later in the article). Thus, it seems to us that the treatment of episodic memory in current discussions of human memory contains a conceptual inconsistency and that an analysis more like the one we have proposed is needed to resolve this inconsistency.

Memory Classifications by Philosophers

In carrying out investigations of memory, philosophers have tended to use a more differentiated classification scheme than that of psychologists. The first modern philosophical discussion of the issues is that of Henri Bergson (1911). Bergson distinguished two forms of memory, "memory par excellence" and "habit memory"; these correspond fairly closely to our personal memory and skill memory. Bertrand Russell (1921) retained the division of memory into two forms. His "true memory" and "habit memory" are quite close to our personal memory and skill memory.

In somewhat more recent times a number of philosophers added memory for knowledge into their classification schemes and have adopted a distinction that corresponds to our personal memory, semantic memory, and skill memory. Furlong (1951) uses the terms retrospective memory, nonretrospective remembering that, and nonretrospective remembering how. Ayer (1956) uses the terms event memory, factual memory, and habit memory; while Locke (1971) adopts the terms personal memory, factual memory, and practical memory.

For the most part these theoretical discussions of memory by philosophers have had little impact on psychological research. However, it is interesting to note that the one recent revision of memory classification, that of Tulving (1972), may derive indirectly from the philosophers. In Tulving's paper he gives credit to an earlier distinction between "remembrances" and

"memoria" by Reiff and Scheerer (1959). This distinction corresponds roughly to our personal vs. nonpersonal memory. Examination of the section of the Reiff and Scheerer monograph on memory distinctions shows that they based their treatment on the early work of Bergson, thus showing a fairly direct link between the episodic/semantic distinction and the philosophical tradition.

There is a striking contrast between psychology and philosophy in what types of memory have been the focus of interest. Most of the first 80 years of research on memory in psychology were directed at the problems of rote verbal skill. (There were exceptions, such as the work on memory of the Würzburg psychologists, of the Functionalists in the United States, and of the Gestalt psychologists.) The emphasis on skill by psychologists was driven by methodological and metatheoretical considerations. The study of semantic memory seems to require the introduction of abstract entities, the study of personal memory seems to require the introduction of mental images; and neither of these was acceptable to most memory researchers during this period. The research of Collins and Quillian (1969) and Rumelhart, Lindsay, and Norman (1972) opened up the study of semantic memory in psychology, and the present chapter argues for empirical work on personal memory.

The philosophers have taken a very different approach. In general, they have tended to find skill the least interesting

form of memory. Initially, with the work of Bergson and Russell the focus was on personal memory. Thus, for example, Russell called personal memory "the essense of memory" (p. 167). In the more recent work philosophers have continued to discuss the problem of personal memory and its degree of veridicality, but they also have focused on the problems of memory for knowledge.

Our conclusion from this brief historical sketch is that current experimental and theoretical work on memory by psychologists should be more pluralistic. In particular, more attention should be given to the study of personal memory.

A STRUCTURAL ACCOUNT OF HUMAN MEMORY

Purpose

The purpose of this section is to develop a more analytic account of the structure of human memory. In this section we attempt to work out the logical possibilities of the forms of human memory instead of simply describing a number of types that occur in our normal interchange with the world. We also intend our structural model to reflect some aspects of the processes that lead to various types of memory representations. Finally, we try to follow our own suggestion and take the data of phenomenal experience as a fundamental aspect of a description of the structure of human memory.

Overview of Structural Account

The essence of our organization of memory is given in Table 2. This table is structured with types of input to the memory

system along the top and types of acquisition conditions along the side. Within the cells are the hypothesized mental events resulting from the conjunction of the particular type of input and type of acquisition condition.

Insert Table 2 about here.

Acquisition Conditions (Rows)

We consider three important types of acquisition conditions: exposure to a single instance of the input, exposure to multiple instances of the input without variation (e.g., ten exposures to the same picture or ten trials on the same serial list of nonsense syllables), and exposure to input that is repeated with variation. The category of repetition with variation is intended to cover a range of levels of abstraction of the input. Thus, multiple exposures to the same dog in various circumstances would be repetition with variation and so would the more abstract level provided by exposure to a number of instances of different types of dogs.

When analyzing the types of memory in the single instance condition we will assume that the memory tasks will be directed at information specific to the single instances. In analyzing the types of memory in both of the repeated items conditions we will assume that the memory tasks will be directed at recall that

utilizes the experiences with the set of repeated items and not at one of the instances.

In each input condition we have divided the resulting mental events into imaginal events and nonimaginal events. This is motivated by our desire to treat the phenomenal data as a serious part of theory construction. Note that the division is between imaginal and nonimaginal and not between phenomenal and nonphenomenal. We adopted this approach primarily for methodological reasons. We believe that there are phenomenal states that are nonimaginal (e.g., the imageless thoughts of the Würzburg psychologists, Woodworth, and Binet; see Calkins, 1909; Humphrey, 1951; Ogden, 1911). However, this is a difficult area and the data have been hard to interpret (see Pani, 1983). Thus, until clarifying data are obtained on this issue, we will restrict our analysis primarily to phenomenal reports of mental images, where the data are clearer and easier to obtain.

In most cases the types of mental representations we postulate for the nonimaginal cells are schemas (Brewer & Nakamura, in press; Minsky, 1975; Rumelhart, 1980; Schank & Abelson, 1977). Schemas are nonphenomenal mental representations of organized knowledge. When an input occurs and activates a schema, then the organized knowledge can be related to the input. This process makes possible: expectations, inferences, and active anticipations. The term "schema" will be used to cover a wide range of knowledge structures--from object schemas that

allow one to infer what the nonvisible side of an object might look like, to motor production schemas which allow the smooth output of a particular motor action.

This discussion of schemas raises an interesting problem. How do these abstract schemas differ from the "abstract knowledge" that we referred to in our discussion of semantic memory? It may be that these two types of mental representation should actually be considered to be of one type. However, we would like to distinguish between them. We propose that semantic memory is knowledge of abstract things, whereas schemas are abstract knowledge of things.

Types of Input (Columns)

The columns in the analysis are organized according to our view of the fundamental types of input that lead to the various forms of memory representation. In those cases where the input involves forming a representation of a content from the external world, we have subdivided the input into meaningful stimuli and meaningless stimuli. We do this because there are important differences between memory for meaningful stimuli, which are easily encoded into preexisting schemas, and memory for meaningless stimuli, which are more difficult to encode into such schemas. In addition, the distinction is of practical value, since how one interprets a particular memory experiment is frequently determined by the nature of the input with respect to this distinction.

A Structural Theory of Human Memory

In this section we examine the hypothesized mental events resulting from the conjunction of the particular types of input and types of acquisition condition. We will proceed through the table by types of input (i.e., column by column).

Visual-Spatial

Meaningful. We postulate that a single exposure to a meaningful visual-spatial input will lead to a particularized visual image. This is, of course, one of the strong components of personal memory as described in the botany of memory.

In his classic review of introspective methods for the study of mental imagery, Angell (1910) suggests that brief exposure to an arbitrary array of objects or pictures, followed by a memory task requiring information about the concrete properties of the display, is one of the best ways to elicit visual imagery (also see Kuhlmann, 1909).

There have been a number of recent experiments examining memory for single exposures to meaningful visual-spatial input (e.g., Brewer & Treyens, 1981; Hock & Schmelzkopf, 1980; Mandler & Parker, 1976) but these experiments rarely include data concerning the phenomenal experiences of the subjects during the recall task. However, from the informal comments of the subjects in the Brewer and Treyens experiment on memory for rooms and from the fact that they sometimes pointed to an imaginary position in space when answering a question, we think that appropriately

designed experiments will support the assertion that this type of input leads to particularized visual image representations.

The mental images associated with personal memory appear to be very vivid and to include much "irrelevant" detail. It is not clear that one can show increased recall of information based on these mental experiences. However, if one could show such evidence in recall, then one might want to hypothesize that the representations for personal memories are less reworked by schema processes and somehow closer to the initial perceptual input than other forms of recall. This difficult and controversial issue is clearly in need of additional study.

Exposure to a single instance of a meaningful visual-spatial input leads to schema instantiation. The individual uses generic schema information to interpret the particular visual-spatial input. The resulting instantiated schema representation consists of an integration of the information contained in the new instance and information from the generic schema. Thus, in the Brewer and Treyens (1981) experiment subjects attempted to recall an office in which they had been for a brief period. The information given in recall was a mixture of information that was clearly from the particular room (e.g., it contained a Skinner box) and information that was not actually in the particular room, but was derived from their general office schema (e.g., it contained books). Note that the case of schema instantiation is part of the larger issue of the interaction of particular input

with generic knowledge. It is likely that both generic visual images and generic schemas can interact with the information contained in input from single instances to produce partially reconstructed visual images and instantiated schemas (e.g., Neisser, 1981, 43-48).

Multiple exposures without variation of a meaningful visual-spatial input should lead to a more articulate image. However, if there is a consistent focus of attention on particular items or properties, then the meaningful nature of the material may lead to a reduction from the image of less relevant properties. Thus, while we would expect context to occur in the visual-spatial component of a personal memory, it may not always remain in cases of multiple exposures.

If an object or class of objects is repeated with variation we postulate that a generic visual image results. This is a topic that needs research. For highly variable classes such as "furniture" it seems unlikely that one forms a generic image (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976); for other less variable classes (e.g., "dog," "triangle") more data are needed. Essentially we are assuming that the process of abstraction (e.g., Gibson, 1969) leads to the production of generic images from experience with multiple differing particulars.

This suggests an interesting problem. Does the process of abstraction lead to a generic image and multiple particular

images or is there loss of the particularized images? Medin and Schaffer (1978) have proposed a theory of concept classification that emphasizes recall of specific instances. Brewer and Dupree (1981, 1983b) have carried out an experiment on the development of generic place representations and have found that there is apparently some loss of the particularized instances that go into making up the generic representation. Clearly another area that needs additional research.

When meaningful visual-spatial inputs are repeated with variation we assume the development of schemas in addition to generic images. The reason that we postulate nonimaginal schema representations for objects and places is that we do not think generic images are abstract enough to account for much of our visual-spatial knowledge. We feel that there is abstract knowledge about objects and places that is somehow specific to them and not a part of semantic memory. Thus, for objects we would consider the classic Piagetian object schema to contain a nonimaginal schema component. For places, consider the following question, "Which is closer, your bathroom or the post office?" It seems to us that one may answer this question with nonimaginal place schema information and without generic image information or information from semantic memory. These are difficult problems and clearly more theory development is needed to make progress on these issues.

Meaningless. We turn now to the second column in Table 2. A meaningless visual-spatial input is one that has little schema information already existing in long-term memory. We assume that exposure to stimuli of this type results in an attempt to build a new schema or impose an old schema (see Piaget, 1952, 1954; Rumelhart & Norman, 1977). Our position here is similar to that taken by Bartlett (1932) in his discussion of the use of nonsense syllables in memory experiments. Bartlett argued that when faced with "meaningless" material subjects would attempt to impose meaning on the stimuli. He referred to this process as "effort after meaning" (p. 20). In more recent times investigators in the Ebbinghaus tradition have shown, in some detail, the powerful effects that effort after meaning has on learning meaningless linguistic material (Montague, Adams & Kiess, 1966; Prytulak, 1971).

The property of meaningless items that makes them meaningless is that the imposition of prior schemas is only partially successful. Thus, to the degree that schema instantiation is inadequate, material must be newly learned from immediate perception. Several investigators have pointed out that the memory for such cases should be relatively imagistic and depictive, since no other form of memory representation is available (Kosslyn, 1980, 1981; Kosslyn & Jolicoeur, 1980; Pani, 1982, 1983).

The occurrence of repetition with variation of instances of an initially meaningless pattern should lead to the development of a new generic image and a new schema. The classic experiments of Posner (Posner, 1969; Posner & Keele, 1968) on recognition memory for dot patterns generated from an underlying pattern represent an attempt to study this process. Posner (1969) suggests that the form of representation in these tasks may be abstract nonimaginal schemas. From our perspective it would be interesting to carry out these experiments in a recall paradigm, with a variety of types of schemas, and obtain phenomenal reports from the subjects during recall. Do the subjects report generic mental images, images of particular instances, or no images at all?

Visual-Temporal

Meaningful. We now begin the third column. We assume that a single exposure to a meaningful visual-temporal event leads to the development of nonimaginal schemas. Observed causal events lead to event schemas and observed goal-directed actions lead to plan schemas (cf. Schank & Abelson, 1977). An empirical study of memory for goal-directed actions by Lichtenstein and Brewer (1980) supports our assumptions on this issue. These investigators had subjects view a videotape of an actor carrying out a series of goal-directed actions and showed that a wide range of recall data could be accounted for by assuming that the subjects had developed plan schemas for the observed actions.

There are few data on the imaginal properties resulting from observed visual-temporal events. Lichtenstein and Brewer (1980) did not, unfortunately, gather any systematic data on this issue. However, some informal observations during those experiments suggest that rarely do subjects report the phenomenal experience of being able to "replay in their mind's eye" a smooth version of what they saw. Instead, they tended to report sequences of static images with some limited movement.

An early discussion of mental imagery by Ladd (1894) supports this view. Ladd believed that the progressive "condensation" of imaginal representation extended in time is a fundamental principle of the development of cognition. Pani (1983) has suggested that the deletion of redundant material from the imaging of visual-temporal input would result in savings of time and effort. These claims are reminiscent of the views of Attneave (1954) and Hochberg (1968) on the perception of visual-spatial structure. They point out that there are particular parts of items that convey relatively large amounts of information about the nature of an object, and other parts that are relatively uninformative. This suggests that the remaining information in the imaginal representation of visual-temporal inputs consists of images of the more informative stages of events.

On the basis of these various considerations we have tentatively assumed that single exposures to meaningful visual-

temporal events lead to sequences of static visual images, rather than to single temporally continuous images. This view contrasts with the inclinations of much current imagery theory (e.g., Kosslyn, 1980; Shepard, 1978), although Kosslyn does discuss the "blink" transformation. Clearly more data are needed here.

If a meaningful sequence is repeated without variation, we assume that it may be converted into a more rigid script. Examples of events repeated with little variation might be religious rites and mechanical processes. Again, we have no data relevant to the issue of the imaginal consequences of repetition without variation. However, it is possible that condensation may continue for irrelevant properties. We would also suspect that repetition would lead to stronger visual imagery for the information that is retained.

For meaningful events repeated with variation we assume the development of more abstract plan and event schemas (Schank & Abelson, 1977; Schmidt, 1976). It is not clear what the imaginal properties would be for this condition. It is likely that even after a great deal of condensation, highly informative generic reference points remain imageable. However, it also is possible that events can differ enough among themselves so that they are encoded at a level of abstraction that cannot be captured in an image.

There is a subset of meaningful visual-temporal events that we wish to distinguish--memory for personal actions. After an

individual has carried out some goal-directed action, the individual can recall what he or she did. This type of recall seems similar to the recall of the actions of another person. However, the actor has direct access to the actor's plans, to knowledge about intentions not acted upon, and to other aspects of conscious mental life that occurred during the action. We will provisionally assume that memory for personal actions can be treated as essentially similar to memory for the observed actions of others.

Meaningless. We assume that subjects exposed to meaningless visual-temporal events will attempt to impose causal and plan schemas on the events. However, there will be numerous cases where unique perceptual properties of a particular event are remembered. As we have argued before, imagery may be the primary way in which such properties as these will be represented at first. A recent experiment by Brewer and Dupree (1983a) supports these assumptions. Brewer and Dupree obtained data showing that subjects attempted to provide plan schemas for relatively meaningless actions and that when they did it improved recall. No phenomenal report data were obtained in this experiment; however, the recognition data and the overall pattern of results can be used to draw inferences about the imagery for meaningful and meaningless actions. It is possible that after viewing an action there is visual information that is retained over a period of hours, but that after several days the information is greatly

reduced and underlying plan information is predominantly what is retained.

Auditory (Nonlinguistic)

The auditory input conditions were filled in by analogy with the visual columns. We have little specific to contribute to the analysis of this type of input, and have included it primarily for consistency. However, there are a number of studies that suggest that the auditory columns will be analogous to the visual columms (e.g., Garner, 1974; Williams & Aiken, 1975).

A complete description of memory would also include an account of memory for music. This is a complex issue. For example, we suspect that an analysis of music should share some of the characteristics of our analysis of linguistic input. However, we know so little about these issues at the present that we are not willing to speculate.

Emotional Situations

In an earlier version of this article we omitted memory for emotions because so little is known about the topic. However, we have decided to include it because just making the attempt seemed to force us to ask interesting questions. In one of the few recent discussions of memory for emotions, Bower (1981) proposes that memory for emotions should be analyzed in terms of "emotion nodes." Given the framework adopted in this chapter there are additional issues that must be resolved. Does the memory for an emotion have an emotion reliving component (an "emotional

image"), and does the memory for an emotion have a nonimaginal "emotion schema" component?

There are formidable problems here. For example, if one attempts to carry out introspective studies of memory for emotion, it is necessary to distinguish the current emotions from the recalled emotions. The problem arises due to the fact that recalling a situation that made you angry can cause you once again to become angry about the situation. Try recalling "your most embarrassing moment" for an intuitive example of the difficulty.

A second issue is a theoretical one. What does it mean to talk about "emotion schemas"? Clearly one can come to have semantic knowledge about any type of input in our table. Thus, one can explicitly enter into semantic memory the fact that "the state to the south of Oklahoma is Texas." Similarly, one can have semantic knowledge that "I was angry when I received the letter last week." The theoretical puzzle is whether it makes any sense to postulate something called an emotion schema independently of the knowledge that you felt a particular emotion. The most sophisticated treatment of this issue that we know of is by St. Augustine. In the Confessions, Augustine discussed the representation issue we just outlined, and he rejected (on the basis of his own introspections) the view that one relives an emotion when remembering it. However, he also rejected the view that one simply has semantic knowledge of the

emotions. He postulated a third form of representation, "notions," to deal with the problem. In our terms, he was apparently suggesting that memory for emotions consists of emotion schemas without emotion images or semantic memory of emotions. Obviously, the issue of memory for emotion is in need of empirical and conceptual clarification.

Linguistic

Special properties of language. Memory for linguistic input is the most thoroughly studied area in the experimental study of memory. It is, however, one of the most subtle in terms of the structure of memory. First one has to take into account that language input can be used to convey many different types of information. This means that, in remembering what was conveyed by a linguistic input, the memory representations themselves may not be linguistic in form. Brewer (1980) has argued that descriptive discourse is represented in terms of visual-spatial schemas, while narrative discourse is represented in terms of plan schemas. There is considerable experimental evidence that can be interpreted to support this assertion. In a study by Bransford, Barclay and Franks (1972) subjects given sentences describing objects in simple spatial arrangements produced recall data that was similar to what one might have expected if the subjects had actually seen pictures of the scenes described by the sentences. For narrative discourse, Lichtenstein and Brewer (1980) have carried out an explicit test. In Experiments 4 and 5

of that paper subjects were given narratives describing a series of goal-directed actions. The pattern of recall data was essentially the same as that produced by subjects who saw actual videotapes of the goal-directed actions. Thus, for our purposes, any time linguistic input conveys information characteristic of some other type of input we will assume that the form of representation in memory is the form postulated for that type of input (e.g., visual-spatial for linguistic descriptions). For example, in terms of Table 2 this approach means that meaningful linguistic input of narrative form should be analyzed as if it occurred in the visual-temporal (meaningful) input column. Note, however, that we do not assume such a shift for expository text. Brewer (1980) has argued that the underlying representations for expository text are abstract propositions or thoughts. To put it another way, expository text is linguistic input that encodes semantic memory information.

A second way in which meaningful linguistic input differs from the other forms of input is that we assume that, in addition to perceptual images (e.g., the sound of a word), there are two abstract levels of representation arranged in a hierarchical fashion: surface structure production schemas, and thoughts. In particular, we are making the assumption that there is a separate abstract level of representation that is a nonimaginal surface structure production schema. This allows the overt recall of a nonsense syllable such as DAX without imaging that syllable

first. This contrasts with the view that surface structure must be encoded in terms of auditory or visual images. Thus, from our perspective the auditory occurrence of a meaningful word such as "truth" leads to three levels of representation: an auditory image, a surface structure production schema, and the thought (meaning) expressed by the word.

Meaningful. Our mode of analysis leaves memory for expository linguistic input with no image properties. We have assumed that the basic meaning for this material is in terms of abstract nonimaginal thought. Imaginal representation of the visual or auditory properties of the presented word would be treated under memory for surface structure information. If the word were concrete and gave rise to visual imagery then that would be treated under memory for visual-spatial information. As mentioned earlier, we believe that one may want to consider the existence of phenomenal but imageless thoughts for this type of representation, but for now we will ignore that possibility. Our analysis of the representation of meaningful linguistic input in terms of an abstract nonimaginal representation is consistent with the standard approach in current cognitive psychology (e.g., Anderson & Bower, 1973; Bransford & Franks, 1971; Kintsch, 1974), and with the earlier work on imageless thoughts (of Calkins, 1909; Humphrey, 1951; Ogden, 1911).

There is a large experimental literature on memory for thoughts supporting the position outlined above (Anderson, 1974;

Bock & Brewer, 1974; Brewer, 1975; Graesser & Mandler, 1975; Sachs, 1967). The typical approach in these experiments is to give subjects a sentence memory task (recall or recognition) and to show that the subjects retain the ideas expressed in the sentences even when they do not retain the particular input surface form.

We have included abstract nonimaginal representations under the heading of input from meaningful expository linguistic discourse because that is probably the most frequent form of input for these processes. However, we believe that information can enter the system of abstract nonimaginal representations (semantic memory) through a variety of nonlinguistic interchanges with the world and through internal reworkings of the information already in the system.

When one has a single exposure to a trivial piece of knowledge it is easy to become confused about the appropriate form of representation (thought vs. surface structure). Take the example of someone who has learned the names of the state capitals so that when given "Illinois," this individual says "Springfield." We would argue that this performance typically requires two levels of representation (surface structure and thought) and so should be distinguished from the case of learning to say "DAX" when given "ZEQ." Evidence that some abstract factual knowledge had been acquired in the first case would be shown by the individual's ability to paraphrase the information

and draw inferences. Thus, having learned Illinois—Springfield our subject could paraphrase the information, "Springfield is the capital of Illinois" or "The capital of Illinois is Springfield." Similarly the subject should be able to make the inference that "Chicago is not the capital of Illinois." Note that for someone who did not know English the ability to give "Springfield" when presented with "Illinois" would be merely an example of memory represented in the form of a surface structure production schema.

The effect of repetition with variation for meaningful linguistic input can have a different effect than it has for the other inputs. There is not necessarily a shift toward more abstract representations. With even a single instance of expository language the initial representation is already abstract, and its content may be extremely abstract (e.g., "Religion stems from the need to know"). When there is repetition with variation there is an increase in the richness and complexity of the representation.

Meaningless (surface structure). We postulate that after exposure to a single instance of a meaningless linguistic input individuals have an auditory or visual image representation. Some of the early introspective studies of memory support this position (Fernald, 1912).

In addition to image representations, a single exposure to a meaningless linguistic input leads to the beginning of a surface structure production schema. The development of surface

structure production schemas for more than a few items is a skill that takes a number of repetitions to develop. The contrast between the ability to produce thoughts and to produce surface structure schemas was noted by Ebbinghaus (1885/1964, p. 50), and was studied by a number of investigators as the difference between "logical" and "rote" memory (Cofer, 1941; Welborn & English, 1937).

For purposes of clarity we have been using examples of meaningless linguistic input to discuss the development of surface structure production schemas. However, because of the hierarchically organized nature of the two forms of linguistic representations, one can also investigate the development of surface structure production schemas for meaningful sentences. There is a wide range of studies showing that for meaningful sentences the memory for the underlying thoughts is better than the memory for the surface structure (e.g., Brewer, 1975; Sachs, 1967).

Consideration of what it means to repeat a surface structure with acceptable variation (change the type face, shift speakers) shows that this type of input does not lead to the same level of abstraction as the other inputs.

There is one area where rote linguistic skill is very important. Each native speaker of a language has to master the tens of thousands of lexical forms that make up the vocabulary of the language. Clearly the ability to develop surface structure

production schemas plays a crucial role in learning a spoken language.

Cognitive Operations

Cognitive skills involve the execution of practiced cognitive operations.

Cognitive skills differ from rote skills in that cognitive skills are generative and rote skills are not. Once an individual has learned a cognitive skill that individual can typically apply it to a large class of new objects (e.g., taking square roots); but once an individual has learned a rote skill that individual has the ability to produce only one set of surface structure objects. The rote skill of saying the multiplication table in English does not allow one to say the alphabet.

The distinction between cognitive skill and recall of information from semantic memory can sometimes be unclear. We tend to classify a task as an instance of cognitive skill if the task is procedural, if it is knowledge how rather than knowledge that. The difference is clear in the case of the rules of syntax of one's native language. A child has the cognitive skill of performing many syntactic operations before entering school and in the course of formal education the child comes to develop knowledge that about some of the rules. This is presumably the distinction that Chomsky was intending when he stated, "a generative grammar attempts to specify what the

speaker actually knows, not what he may report about his knowledge" (1965, p. 8).

There has recently been a renewed interest in the study of cognitive skill in psychology (Anderson, 1981; Card, Moran & Newell, 1980). Cognitive skills, like the other skills, require a number of repetitions before smooth, successful operation. Thus, it is difficult to discuss the representation that results after a single operation of a cognitive skill. However, in a recent study of the early stages of learning to use a text editor Ross (1982) has obtained verbal protocols suggesting that the subjects attempt to supplement the missing cognitive skill with other types of knowledge. They use personal memories, "Oh yes, I remember when I pressed that button over there the whole screen went blank" and semantic knowledge "Let's see, the rule is that to change a word in the text, select the word, press capital 'R', type the new word and press the ESC key." One has the feeling that what is going on here is similar to Bartlett's "effort after meaning," perhaps "effort after production."

When cognitive operations have been repeated many times there is little or no imaginal accompaniment (Book, 1908). It is presumably this observation that led Lashley to state "No activity of mind is ever conscious" (1960, p. 532). It may be the case that cognitive operations are a type of mental occurrence that is intrinsically nonphenomenal. On the other hand, it may be that they are phenomenally experienced only

during the early stages of the acquisition of a skill and not later on (see Pani, 1983).

Motor Performance

The issues relating to the acquisition of motor skill are similar to those discussed for cognitive skill. Many investigators in this area have suggested that, when motor actions have been practiced, the conscious correlates of performing the action are reduced or eliminated (Adams, 197?; Book, 1908; Fitts & Posner, 1967). The classic discussion is in James' chapter on habit. He states, "habit diminishes the conscious attention with which our acts are performed" (1890, Vol. 1, p. 114). While there is agreement that conscious processes occur during the early stages of the acquisition of a motor skill, it is not clear exactly what types of processes these are. For example, they may be motor imagery, imageless thoughts, or other types of memory representation used in "effort after production."

Plan Production

The carrying out of intended activities involves the production of complex sequences of actions (e.g., driving to a new restaurant). We assume that these intentional actions are structured in terms of plan production schemas. Plan production schemas organize actions in terms of hierarchically structured goal-subgoal relations. Plan production is intended to allow us to include the memory component that is involved in: walking

home from the office, baking a cake, dancing in a square dance. One might want to argue that plan production is a complex mixture of cognitive operations and motor performance, but we prefer to treat plan production as a separate category.

Carrying out a single instance of a new plan seems to be a memory task in only a limited fashion. In performing a new plan, say finding your way for the first time from Heathrow Airport to the British Museum, much of the performance seems to be problem solving with very general generic memory input. It is not clear how much imaginal activity occurs when one carries out a new plan of this type, but there does appear to be a large amount of nonimaginal phenomenal experience. It seems to us that one is aware of intentions, the goal, and many subgoals (e.g., "I need to get from here to the museum . . . I wonder how I can get my money changed . . . How do I get to the underground, etc.").

In plans carried out with little variation (taking the same route home from the office every day) it would appear that the awareness of the subgoals and subplans tends to decline (Shallice, 1972). It seems likely that it is these fixed plans that are most likely to lead to "actions slips" (Norman, 1981) where the individual carries out an action that was not intended. Carrying out a variety of intentional actions of a given type leads to the development of generic plan schemas (e.g., going to restaurants, traveling to new cities).

STRUCTURE OF MEMORY: IMPLICATIONS

In this section of the chapter we will relate the earlier, more descriptive botany of memory to our analysis of the structure of memory. We will also work out some of the implications of our structural account for a number of particular issues in the study of human memory.

Relation of the Botany of Memory (Table 1) to the Structure of Memory (Table 2)

Our intent in outlining the botany of memory was to describe common types of human memory. Our intent in the structural account was to give an analytic account of possible types of human memory along with some indication about how different forms of memory are acquired. We think that the types of memory discussed in the botany are the ecologically important subset of the possible types of memory given in Table 2. They are the subset that tends to occur in the normal ecological interactions with the environment.

In moving around in the world one tends to be exposed to many unique co-occurrences of meaningful visual-spatial input, meaningful visual-temporal input, meaningful auditory input, and linguistic input. It is roughly this set of representations (the single instance rows in Table 2) that go into making up personal memory. In our dealings with the world, and in particular in our dealings with the products of culture, we are exposed to much abstract knowledge (facts, propositions, thoughts). It is this

type of knowledge that constitutes semantic memory (the meaningful linguistic input column). In moving through the visual world, we tend to view constant objects and constant places in the environment from a variety of perspectives. It is this type of interaction with the world that leads to the development of generic visual memory (the repeated with variation rows in the visual-spatial input columns). In learning to speak a language and in memorizing nonsense syllable lists for experimental psychologists, we develop the surface structure production schemas that make up rote linguistic skill (the repeated without variation rows in the meaningless linguistic input column). In carrying out some of the complex repetitive processes that are part of modern civilization (arithmetic, text editing) we come to develop cognitive skills, and finally when we repeatedly manipulate objects in the world we come to develop motor skills. Thus, by taking the analysis of the structure of memory, and looking at naturally occurring human actions, we find the botany of memory to be a natural consequence of the operation of the human memory system and the normal organism-environment interactions in our culture.

Mental Imagery in the Transfer of Procedural Memory to Semantic Memory

In our analysis of memory we noted that the knowledge involved in practiced skills is represented in production schemas and little imaginal experience is reported during a skilled

performance. However, in the course of pilot work for an experiment on phenomenal experience during memory (Brewer & Pani, 1982, 1983b) we have uncovered an interesting class of mental processes. If one asks a subject for a propositional account of information that "resides in" procedural (skill) memory then there is a striking occurrence of appropriate mental imagery. Thus for example:

a. Rote linguistic skill

(1) "What is the seventh letter of the alphabet?"

(2) "What is the next to last digit of your phone number?"

b. Cognitive skill

(1) "What is the sum of 78 and 43?"

(2) "What are the last three letters of the plural of irony?"

c. Motor skill

(1) "Which finger do you use to type an 'r'?"

(2) "When backing a car which direction do you turn the steering wheel in order to make the back of the car go to the left?"

It appears that in these cases one is able to divide one's conscious mental processing into two parts. One part of the mind carries out the procedural task in imagistic form and the other part of the mind notes the contents of the images and gives the required propositional answer. It seems to us that this class of phenomena shows the qualitative difference between knowledge how

and knowledge that and suggests that the mental imagery might play a functional role in performing the memory task.

In the course of everyday life one rarely needs to perform procedural tasks in imagistic form. However, mental arithmetic is an exception. Most mental skills are carried out in interaction with cultural objects (e.g., a computer terminal for text editing; pencil and paper for square roots), and we have argued that during skilled performance little imagery occurs. However, in everyday life one occasionally needs to carry out the task of simple arithmetic without paper and pencil and so resorts to "mental arithmetic" or "doing the problem in your head." In keeping with our account of mentally performed skills, there appears to be strong imagery in this task. The phenomenon is so powerful in this case that when B. F. Skinner (1957) was attempting to work out a radical behaviorist approach to psychology he was forced to note that, "In intraverbal chaining, for example, necessary links are sometimes missing from the observable data. When someone solves a problem in 'mental arithmetic,' the initial statement of the problem and the final overt answer can often be related only by inferring covert events" (p. 434).

Multiple Forms of Representation

One of the obvious consequences of our analysis of memory is that there are many different forms of memory representation. The same event can result in different memory representations (as

in the intial example of the undergraduate going to the psychology experiment), and a given recall performance can be based on a variety of forms of mental representation.

For example, consider a typical semantic memory task where the subject is asked "What color is a canary?" and responds correctly. In terms of our analysis the subject's response could have been based on: (a) a particularized image, (b) a schema (c) a generic image, (d) semantic memory, or (e) rote linguistic skill. Clearly, if one is going to construct adequate models of the memory process one must be sensitive to this issue and attempt to establish what form of representation the subject is using in a given performance (see Kosslyn, 1980, for a similar position).

In general, the proposal we have outlined is going to be hard on the "nothing but" theorist (e.g., the theorist who says that the form of representation is nothing but X). For example, when Begg and Paivio (1969) postulated that abstract sentences are represented in memory as nothing but surface structures, Brewer (1975) was able to show the problems with this position by providing memory data (synonym substitutions) which seem to require an abstract nonimage form of representation in the recall of meaningful abstract sentences.

To take another example, it seems to us that many types of reasoning problems can be solved with both imaginal and nonimaginal representational processes. Thus, in studying

reasoning problems one must find out what forms of representation are being used in a particular performance and why (see Banks, 1977; Clark, 1969; Huttenlocher, 1968; Moyer & Dumais, 1978).

The approach we have adopted here can account for many individual differences in the performance of a given task. When we ask people to tell us the seventh letter of the alphabet we usually get long reaction times and strong reports of auditory and/or visual imagery. However, one individual we tested gave the response immediately and with little report of imagery. When we asked the subject some questions to find out why he differed from our other subjects we found that he was an amateur cryptographer and had the letter-number correspondences stored in rote linguistic form.

To take another example, we have recently tried to elicit personal memory by asking a question such as "What did you have for breakfast?" The subjects tested gave personal memory reports, but suppose that a subject had given a response such as "eggs" very rapidly and with little report of imagery, or feeling of reliving. We suspect that further questioning would show that this subject had eggs for breakfast every day and was using information from semantic memory to answer the question.

Copy Images vs. Reconstructed Images

We find the logical and empirical arguments of Pylyshyn (1973; 1981) and others against pure copy theories of imagery to be compelling. It must be the case that at least part of the

phenomenally experienced image is reconstructed from information of a nonimaginal kind.

We have recently carried out some experimental work on this topic. In an earlier study, Brewer and Treyens (1981) showed that schema-driven inferences occurred in the recall of information about a room that subjects had been in briefly. The subjects frequently recalled having seen books in the room, even though there were no books present. Brewer and Pani (1983a) have replicated the Brewer and Treyens study, but included detailed questions about mental imagery experiences after each recall trial. We found that for present and inferred items of equivalent memory strength the subjects reported roughly equivalent amounts and quality of imagery. In other words, the schema-driven inferences were apparently incorporated into the phenomenally experienced image of the room.

An important area for this issue is the study of autobiographical personal memories. As discussed earlier, these memories are accompanied by a strong belief that they are veridical. Neisser (1982, pp. 43-48) has recently argued that even the intense "flashbulb" form of personal memories resulting from a highly emotional event (e.g., "Where were you when you heard that Kennedy had been shot?") are not veridical. He has also shown that John Dean's recall of specific events at the Watergate hearings was a complex reworking of information from a number of different occasions (Neisser, 1981). Except for

Neisser's study of John Dean, most of the data here remain anecdotal, and the standard techniques for studying autobiographical memory (e.g., Robinson, 1976) do not allow one to resolve this issue. Brewer (1983) has developed a technique which should allow a more careful examination of the veridicality of personal memory. He has subjects carry a random alarm device and has them record what is occurring when the alarm goes off. By comparing personal memories occurring at the time of test with the original record of the event this technique makes possible the gathering of systematic data on the issue of veridicality of personal memory.

CONCLUSIONS

In this article we have tried to take a fresh approach to the problem of human memory. We first attempted to provide a description of the common forms of memory. We adopted this strategy because we think that research in memory has frequently cut short the process of description and moved too soon to the job of detailed analysis and model building.

We have argued, on theoretical grounds, that the data from phenomenal experience should be given equal status with the other forms of data typically gathered in experiments on human memory. In carrying out our analysis we have attempted to provide an example of how this data can be used in theory construction

In working out our analysis of the structure of memory we felt a constant tension between a view of memory as the reliving

of earlier perceptions and a view of memory as a schema-based reconstructive process. We hope the analysis succeeds in providing a synthesis of these two positions.

Compared to other recent theories of memory our position looks somewhat complex. It seems to us that the complexity in our analysis is simply a reflection of the complexity of the problem. We think that many of the classic theories of human memory have achieved simplicity by ignoring the actual complexity of the phenomena and by attempting to give a simple image account, or a simple interference account, or a simple propositional account.

At the end of many sections of this chapter we found ourselves saying that more empirical and theoretical work was needed. We hope that this was not merely ritualistic language on our part and that, in fact, the framework provided in this paper does lead one to see new problems and new issues in the study of memory.

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Table 1

Botany of Memory: Examples

Personal Memory

"When was the last time you spent cash for something?"
"Who was the last person you saw before reading this chapter?"
"Did you see anyone on the ground floor of your office building when you came to work today?"

Generic Memory

Semantic Memory

"What part of speech is used to modify a noun?"
"What is the opposite of falsehood?"
"Which is faster, the speed of sound or the speed of light?"

Perceptual Memory

"In which hand does the Statue of Liberty hold the torch?"
"How many windows are there in your house?"
"What shape are a German shepherd's ears?"

Skill

Motor Skill

Typing a sequence of random letters from copy
Riding a bicycle
Signing your name

Cognitive Skill

Speaking a sentence with a verb in the past tense
Adding a column of two-digit numbers
Using a text editor

Rote Linguistic Skill

Giving your phone number
Multiplying 2 x 2
Recalling a list of nonsense syllables

Table 2. A Structural Account of Human Memory

Acquisition Conditions		TYPES OF INPUT					
		VISUAL-SPATIAL		VISUAL-TEMPORAL		AUDITORY-NONLINGUISTIC	
		MEANINGFUL (Objects, Places)	MEANINGLESS	MEANINGFUL (Events, Actions)	MEANINGLESS	MEANINGFUL (Common Sounds)	MEANINGLESS
Single Instance	Imaginal	Particularized Visual Images	Particularized Visual Images	Particularized Sequence of Visual Images	Particularized Sequence of Visual Images	Particularized Auditory Images	Particularized Auditory Image
	Nonimaginal	Instantiated Schemas	Partially Instantiated Schemas	Instantiated Schemas	Partially Instantiated Schemas	Instantiated Schemas	Partially Instantiated Schemas
Repeated Without Variation	Imaginal	Reduced Particularized Visual Images	Particularized Visual Images	Reduced Particularized Sequence of Visual Images	Particularized Sequence of Visual Images	Reduced Particularized Auditory Images	Particularized Auditory Images
	Nonimaginal	Instantiated Schemas and Development of Rigid Schemas	Partially Instantiated Schemas and Development of Rigid Schemas	Instantiated Schemas and Development of Rigid Schemas (Scripts)	Partially Instantiated Schemas and Development of Rigid Schemas	Instantiated Schemas and Development of Rigid Schemas	Partially Instantiated Development of Rigid Schemas
Repeated With Variation	Imaginal	Generic Visual Images	Generic Visual Images	?	?	Generic Auditory Images	Generic Auditory Images
	Nonimaginal	Instantiated Schemas and Schema Development	Schema Development	Instantiated Schemas and Schema Development (Plans)	?	Instantiated Schemas and Schema Development	Schema Development

Table 2 continued

Acquisition Conditions		TYPES OF INPUT					
		EMOTIONAL SITUATIONS	LINGUISTIC: MEANINGFUL (Expository Discourse)	LINGUISTIC: MEANINGLESS (Surface Structure)	COGNITIVE OPERATIONS	MOTOR PERFORMANCE	PLAN PRODUCTION
Single Instance	Imaginal	Emotion Images	None	Auditory or Visual Images	?	?	?
	Nonimaginal	Emotion Schemas?	Facts Propositions	Incomplete Surface Structure Production Schemas	Incomplete Cognitive Productions Schemas	Incomplete Motor Production Schemas	Plan Productions (Awareness of intentions, goals and subgoals)
Repeated Without Variation	Imaginal	?	None	Little or No Imagery	Little or No Imagery	Little or No Imagery	?
	Nonimaginal	?	Facts Propositions	Surface Structure Production Schemas	Rigid Cognitive Production Schemas	Rigid Motor Production Schemas	Rigid Plans Productions (Awareness of intentions and goals) (Scripts)
Repeated With Variation	Imaginal	?	None		Little or No Imagery	Little or No Imagery	?
	Nonimaginal	?	Thoughts		Generative Cognitive Production Schemas	Generative Motor Production Schemas	Plan Production (Awareness of intentions and goals)